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FEASIBILITY STUDY OF INTEGRAL HEAT SINK SPACE SUIT CONCEPTS

BY
A. P. SHLOSINGER AND W. WOO

PREPARED UNDER CONTRACT NO. NAS 2-2102

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NORTHROP CORPORATION
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3401 WEST BROADWAY
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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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SUMMARY

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This report presents the results of an analytical study to determine feasibility and identify problem areas of a space suit thermal control concept, relying on phase change of heat sink materials, distributed over the suit area, for control of sensible metabolic heat. The performance of materials with melting points below the desirable skin temperature of man with heats of fusion near or above 50 kilocalories/kg (100 BTU/lb) has been evaluated. The formation of a layer of molten heat sink material of low thermal conductivity has been identified as the major factor in limiting suit performance. Several concepts to improve suit performance are presented and evaluated as to their merit for further development work. Feasibility of the basic concept for stated limited operating time periods, and feasibility of the improved concepts has been demonstrated.

author

INTRODUCTION

Present concepts of liquid cooled space suits rely for removal of sensible metabolic heat on conductive and/or radiative heat transfer from the human skin to a solid surface, which is cooled by a circulating liquid. Experimental work performed by the NASA Manned Space Flight Center, by Northrop Space Laboratories (Reference 1) and by others (Reference 2) has demonstrated that this mode of body temperature control is superior to body temperature control by a circulating ventilating gas.

The desire for simplification of space suit thermal control systems has led Northrop Space Laboratories to a concept of body temperature control where the solid surface to which metabolic heat is rejected is temperature controlled by a stationary and passive "heat sink material" rather than by a circulating coolant. The heat sink material is integrated into the suit and distributed over an adequate portion of the body area. It is expected to permit operation of a space suit for limited time periods without the need for a circulating fluid for heat transport from the body to a back (or chest) pack (Figure 1). It could also be used as a means to increase thermal inertia of the man-suit system, or provide local cooling for selected body areas in combination with other means of heat removal. Materials undergoing a solid to liquid phase change at temperatures suitable for human body temperature control, which have a high heat of fusion, have been selected as having a good potential for application as heat sink materials.

The purpose of the research program described in this report is to analytically investigate feasibility and operating time limitations of various physical arrangements and design concepts. This included investigations of the adaption to variations in metabolic heat generation by the astronaut, investigations on the effects of the melting and formation of a molten fusible material layer on heat transfer between the skin and the constant temperature melting liquid-solid interface (Figure 2), and identification of material property requirements and of development work which will be required to advance from the concepts described towards application to hardware.

THE INTEGRAL HEAT SINK SPACE SUIT CONCEPT

Present concepts of gas ventilated or liquid cooled space garments minimize the effects of the external environment by thermally isolating the body of the man in the suit from the external suit surface. Metabolic heat emission from the man's skin is controlled by transporting the heat to a backpack, where the heat is usually rejected in a water evaporator. In gas ventilated suits, the skin is cooled predominantly by evaporation of sweat, and most of the heat is transferred to the backpack as latent heat of the water vapor, which is carried along by the ventilating gas. In liquid cooled suits heat is transferred from the skin to a liquid, circulating in flexible tubes, by conduction, radiation or a combination of both.

The concept of the integral heat sink space suit is similar to that of a liquid cooled suit, except that the heat emitted by the man is not transported to the backpack. Instead, the heat is stored in close proximity to the skin in a material fusible at a

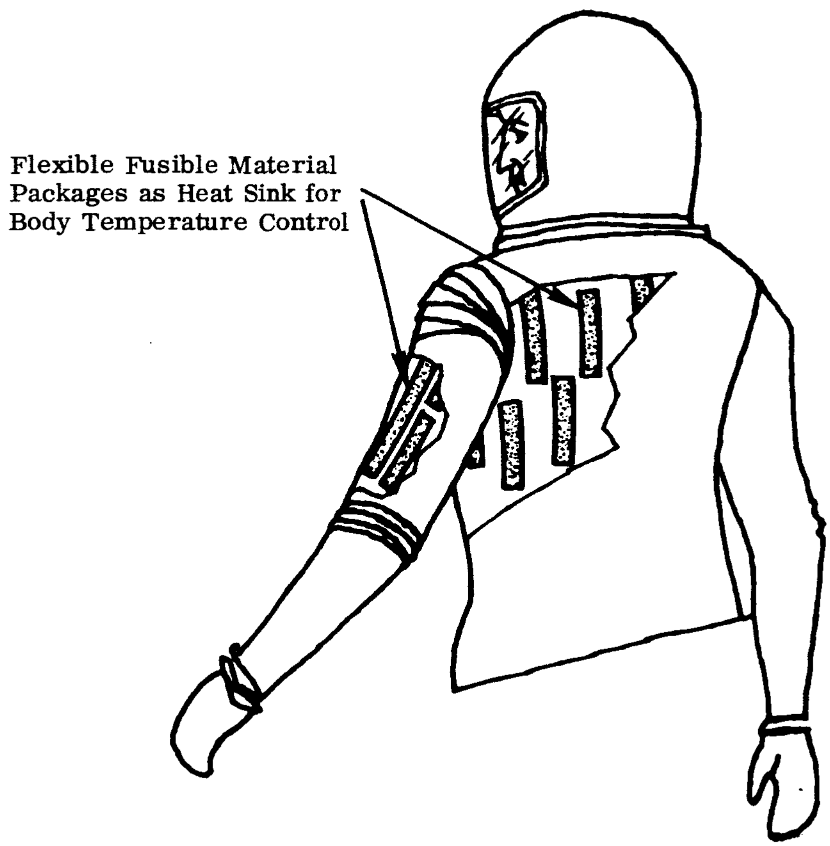
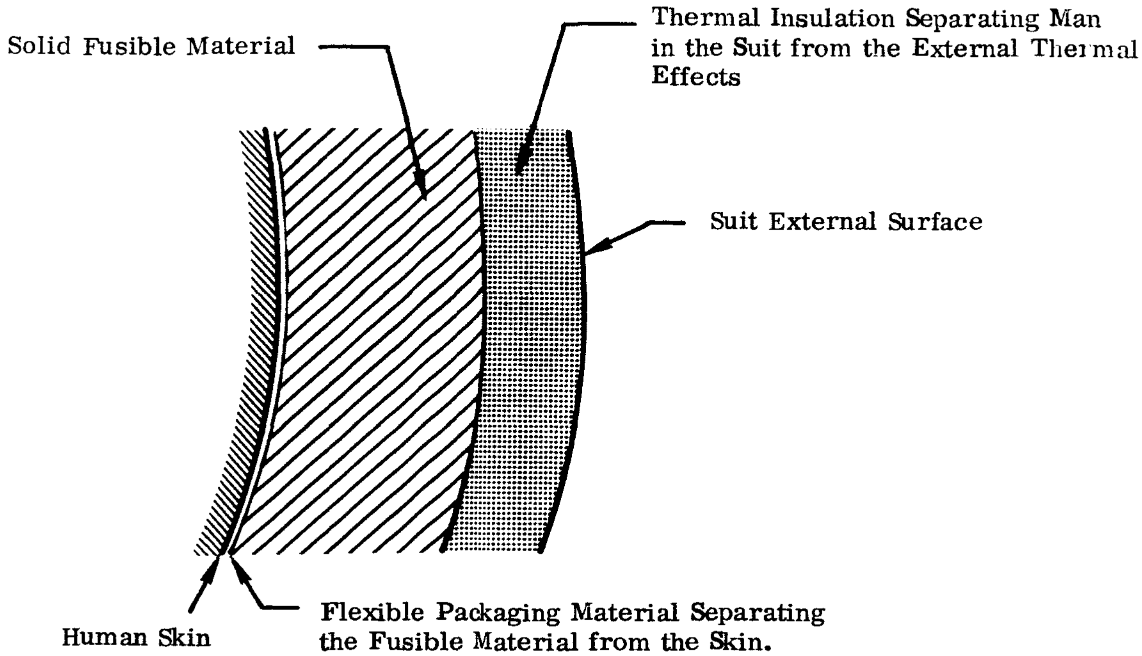
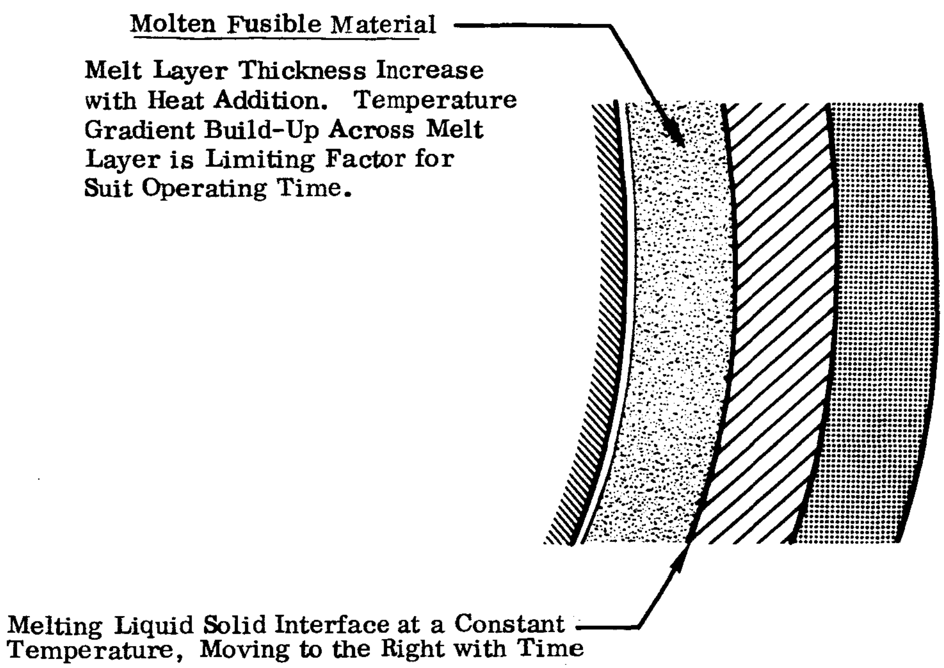


FIGURE 1 A CONCEPT FOR BODY TEMPERATURE CONTROL IN A SPACE SUIT RELYING ON PHASE CHANGE MATERIALS DISTRIBUTED OVER THE BODY



SOLID FUSIBLE MATERIAL AS INITIALLY APPLIED IN SUIT



LIQUID-LAYER BUILD-UP WITH TIME

FIGURE 2 CONCEPTUAL SKETCH OF SCHEME TO REMOVE HEAT BY APPLYING FUSIBLE MATERIAL suitable temperature and distributed in flexible sealed pockets over the inner suit surface. Adequate thermal storage capacity, at a temperature compatible with the comfort requirements of man must be provided for the duration of the mission. In this study, the application of suitable fusible materials as heat sink has been investigated. A suitable melt point, a high heat of fusion and ready reversibility of the melting-solidification cycle are required material properties.

Integration of the heat sink into the suit will eliminate the need for a fluid circulating system with its pump (or blower), liquid accummulator and tubing system and the need for a water evaporator with water storage and expulsion tank, evaporator controls and miscellaneous plumbing. When combined with techniques for passive control of humidity in a space suit, a much simpler suit can be envisioned where the function of the backpack is reduced to the supply of breathing oxygen and pressurization gas and such non-life support functions as communications.

The elimination of the water evaporator and the need for the vacuum of space permits application of the temperature control techniques of a fusible material heat sink space suit to a variety of other protective suit applications, including applications where it may be practical and desirable to periodically supply and reject heat, if the suited man is subjected to cyclic heating and cooling effects resulting from his external environment and/or his activities.

A space suit using fusible materials as heat sink will be stored and regenerated in a low temperature compartment for solidification of the fusible material prior to use. Its mission duration will be limited by the heat storage capabilities of the fusible materials used. Problem areas, some of them common to any type of space suit, such as adapting the cooling system to variations in metabolic rate, will require particular solutions for the fusible material integral heat sink space suit. Limitations caused by the change in heat transfer between the skin and the melting solid-liquid interface resulting from the formation of a low thermal conductivity melt layer require evaluation (Figure 2).

Physical Concept of a Fusible Heat Sink Material in a Space Suit

Two basic approaches to heat transfer have been used in the present designs of liquid cooled space suits. Heat may be transferred from the skin to a cooled inner suit surface predominantly by radiation, or the cooled inner suit surface may be in direct contact with the skin and heat transfer take place predominantly by conduction. For the purpose of this study, heat transfer by conduction from the skin to thin walled sealed and flexible fusible material containers, in direct contact with the skin of the man, was assumed. This concept is not only more efficient in heat transfer, but has a better potential for adapting heat removal rate to variations in metabolic rate.

The containers will be shaped and arranged in a way as not to interfere with mobility. For example, relatively long tubular containers arranged in parallel may be used on the upper and lower arms and legs, leaving joints free to move and permit muscles to expand (Figure 1). Larger flat containers could be used in relatively rigid body areas such as the chest and back. These containers will be individually sealed and independent from each other. Continuous coverage of the body is not required as has been shown in experimentation with liquid cooled suits (Reference 2).

The build-up of the liquid layer resulting from body heat addition has a limiting effect on the suit operating time such that the useful and practical thickness of the containers (in a direction perpendicular to the skin surface) will be in the range of 0.5 cm (0.2 inch).

The material used for the containers will be an elastomer, which will expand and contract as the material inside expands and contracts during melting and solidification. This will maintain the container full and provide thermal contact between container wall and fusible material, which is required for good heat transfer.

Limitations of the Integral Heat Sink Space Suit Concept

Space Suit temperature control systems must provide for the removal of the sensible metabolic heat emission of the astronaut at skin temperatures within the comfort range. This must be accomplished under variations of sensible metabolic heat rate.

The rate at which heat is removed from the skin will depend on the resistance to heat flow between the skin of the astronaut and the constant temperature melting solid-liquid interface, and on the temperature difference between skin and the fusible material melt point. For a constant metabolic rate and a constant resistance between skin and the melting interface, a fusible material could be selected with a melt temperature to provide the temperature difference required for a constant skin temperature.

However, metabolic rate and resistance between the liquid-solid interface and the skin are both variable. The liquid melt layer is a thermal resistance between the astronaut's skin and the melting liquid-solid interface which increases with heat addition, hence with time of suit operation (Figure 2).

It can be stated that minimization of resistance between the skin and the constant temperature melting interface and selection of a fusible material with a meltpoint close to the desired skin temperature will be desirable for satisfactory operation. This becomes obvious if a theoretical boundary case is considered where the meltpoint of the fusible material would be exactly at a selected skin temperature, e.g. 33.1°C (91.5°F) and the resistance to heatflow between melting interface and skin would be zero. Under these assumptions, skin temperature would be constant at any metabolic rate, and only the rate of fusible material melting would change with change of metabolic rate. A quantitative examination of the effects of the liquid melt layer and the melt point of the fusible material selected on adaption of the system to variations in metabolic rate is presented in the THERMAL ANALYSIS section of this report. Conceptual approaches of how to overcome the difficulties of melt layer build-up and adaption to metabolic rate are presented under the heading RECOMMENDATIONS in this report.

THERMAL ANALYSIS

Several fusible materials which have properties that make them suitable as heat sinks for space suit application were selected and their thermophysical properties used in a thermal analysis. The selection of these materials resulted from a data survey and was based upon considerations of melting point, heat of fusion, thermal conductivity, density, toxicity, corrosiveness, fire hazard, and availability of published thermophysical properties data. The data survey was facilitated by the availability of the data of Reference 3. The selected, potentially suitable materials and their thermophysical properties are tabulated in Table I.

It is assumed that adequate thermal insulation will reduce external environmental effects to an insignificant magnitude. The necessary sensible metabolic heat removal required to insure adequate temperature control shall be provided by the endothermic melting of the fusible material.

As the fusible material absorbs heat and melts, a liquid layer forms separating the source of heat from the melting surface of the solid fusible material. A thermal analysis was performed, replacing complex equations associated with rates of melting and a moving liquid-solid interface with a thermal system analog represented by an equivalent electrical circuit using lumped parameters. With this electrical analog, a digital computer solution for melting of a semi-infinite slab was obtained.

One of the boundary conditions assumed was that the rate of heat into the face of the slab (on the skin side) was a constant. Several computer runs were made for various materials and a number of heat rates. The computer results were then presented parametrically in Figures 3 and 4. These parametric data curves are applicable to the materials which were selected and tabulated in Table I. Figure 3 can be used to calculate the temperature gradient across the liquid layer which forms as a function of heat rate and time as heat is added to the fusible material. Figure 4 can be used to calculate the thickness of the liquid layer as a function of heat rate and time. The curves presented parametrically in Figures 3 and 4 have been utilized in developing other curves in this report which present the performance of particular fusible materials in a space suit.

The temperature gradient across the liquid melt thickness of fusible material is shown in Figure 5 as a function of time for two paraffins and water. A sensible heat rate of 201.6 kilocalories/hr (800 BTU/hr) is assumed in this figure. A fixed insulating layer between the fusible material and the skin would provide a temperature gradient such that surfaces contacting the skin would be only slightly below the lowest accepted skin temperature. It is further assumed that 0.93 meter^2 (10 ft^2) of skin area (roughly 50% of the total surface area of an average man) is in contact with fusible material containers distributed over the internal suit surface. 31.1° C (88° F) to 35° C (95° F) is assumed as an acceptable range of skin temperatures. With this range in skin temperature a 3.9° C (7° F) change in temperature gradient across the liquid melt layer will maintain skin temperatures within the comfort range. Figure 5 shows that the temperature gradient across the melt layer will increase from zero to 3.9° C (7° F) in about one-half hour for the two paraffins tetradecane and octadecane. For water (ice) the same temperature gradient increase would occur in 4 hours. The longer suit operating time which could apparently be achieved with water is due to the higher thermal conductivity and the higher heat of fusion of the liquid water, compared to the liquid paraffins (see Table I). The higher heat of fusion results in less melt layer thickness for equal heat input and thereby contributes to lower thermal resistance of the melt layer. The above example examined fusible material performance under the assumption of a constant metabolic heat rate and the apparent superiority of water applies only for this assumption.

TABLE I

PROPERTIES OF SEVERAL SELECTED FUSIBLE MATERIALS*

MATERIAL			PROPERTIES									
	Name	Formula	Thermal Conductivity k_m $\sim \frac{cal\ (gm)}{hr\text{-}cm\text{-}^oC}$	Density ρ $\sim \frac{gm}{cm^3}$	Specific Heat c_p $\sim \frac{cal\ (gm)}{gm\text{-}^oC}$	Melt Temp. Tmelt ^oC $\sim$ (^oF)	Heat of Fusion L $\sim \frac{cal\ (gm)}{gm}$	Toxicity	Irritant	Fire Hazard	Corrosive Properties
PARAFFINS	TETRADECANE	$C_{14}H_{30}$	1.283 @ 5.0^{o}C	0.770 @ 5.0^{o}C	.495 @ 5.0^{o}C	5.0 (41)	54.7	Slight anesthetic when in sufficient concentration to dilute oxygen to point below that necessary to sustain life.	Slight	Slight	None
PARAFFINS	HEXADECANE	$C_{16}H_{34}$	1.288 @ 16.1^{o}C	0.776 @ 16.1^{o}C	.505 @ 16.1^{o}C	16.1 (61)	56.2				
PARAFFINS	OCTADECANE	$C_{18}H_{38}$	1.300 @ 27.2^{o}C	0.777 @ 27.2^{o}C	.517	27.2 (81)	58.2				
	WATER	H_2O	4.74 @ 0^{o}C	1.000 @ 0^{o}C	1.01 @ 0^{o}C	0 (32)	80.0	None	None	None	None

*From References 3, 4, and 5.

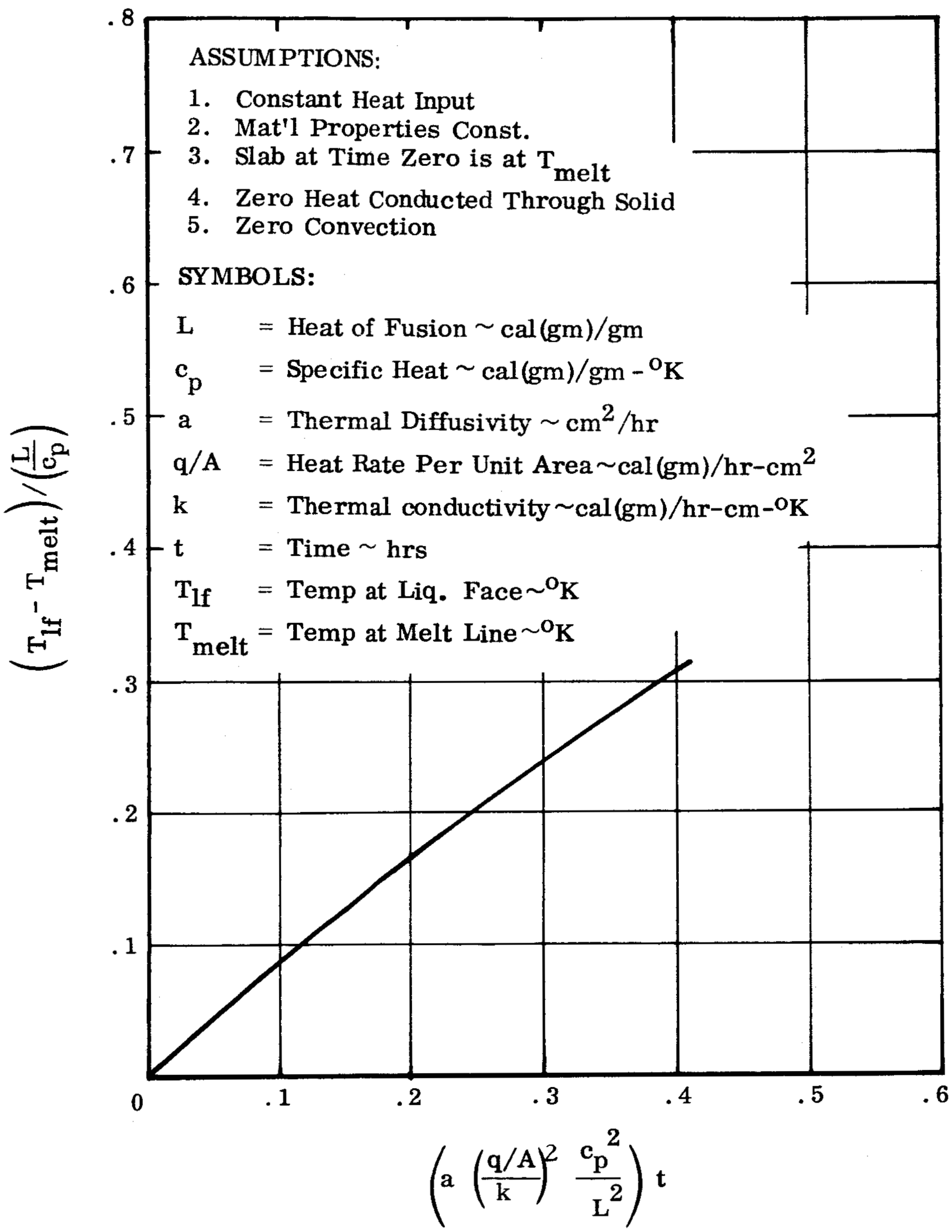


FIGURE 3 TEMPERATURE PARAMETER VERSUS TIME PARAMETER FOR MELTING OF SEMI-INFINITE SLABS

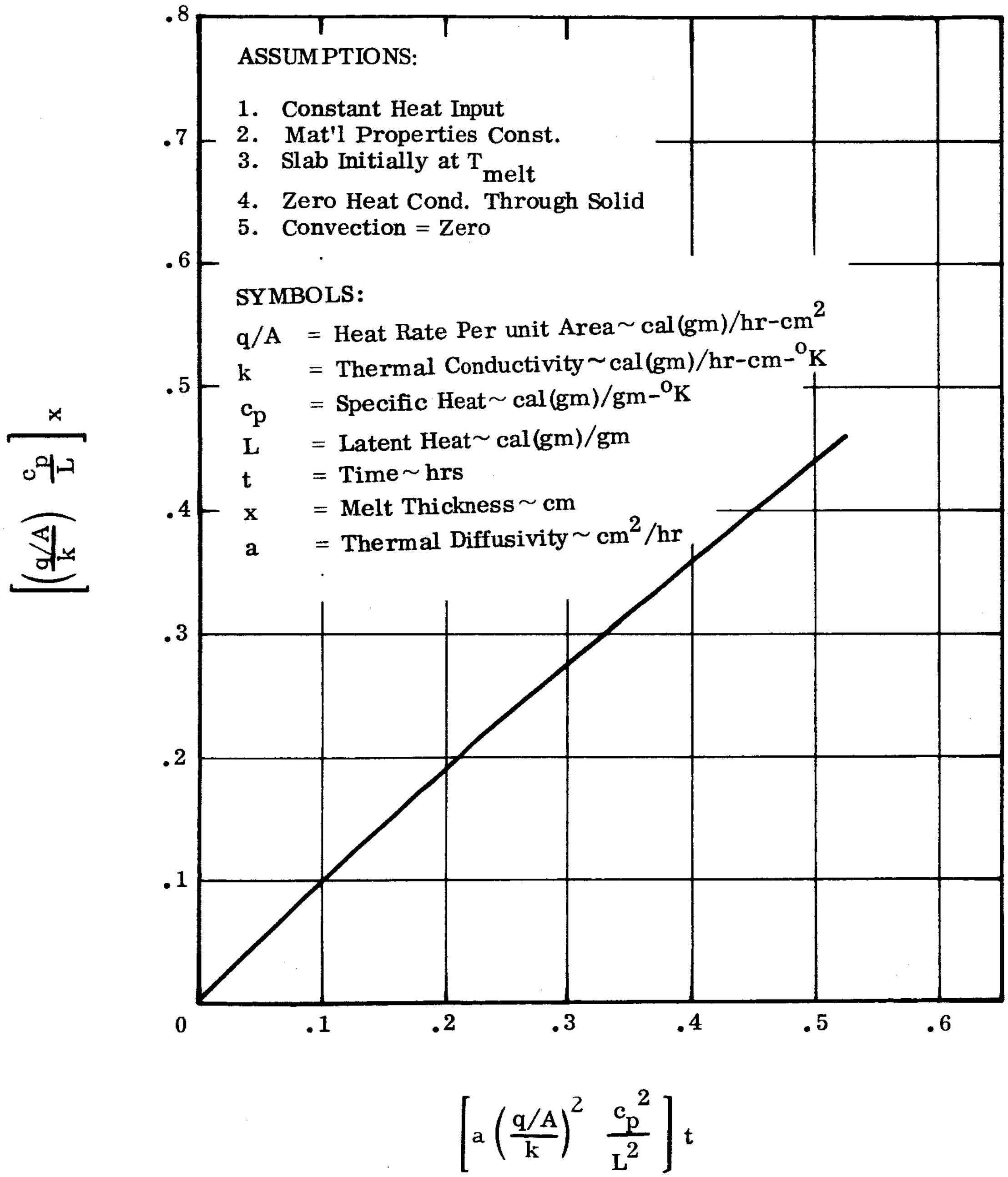


FIGURE 4 MELT THICKNESS PARAMETER VERSUS TIME PARAMETER FOR MELTING OF SEMI-INFINITE SLABS

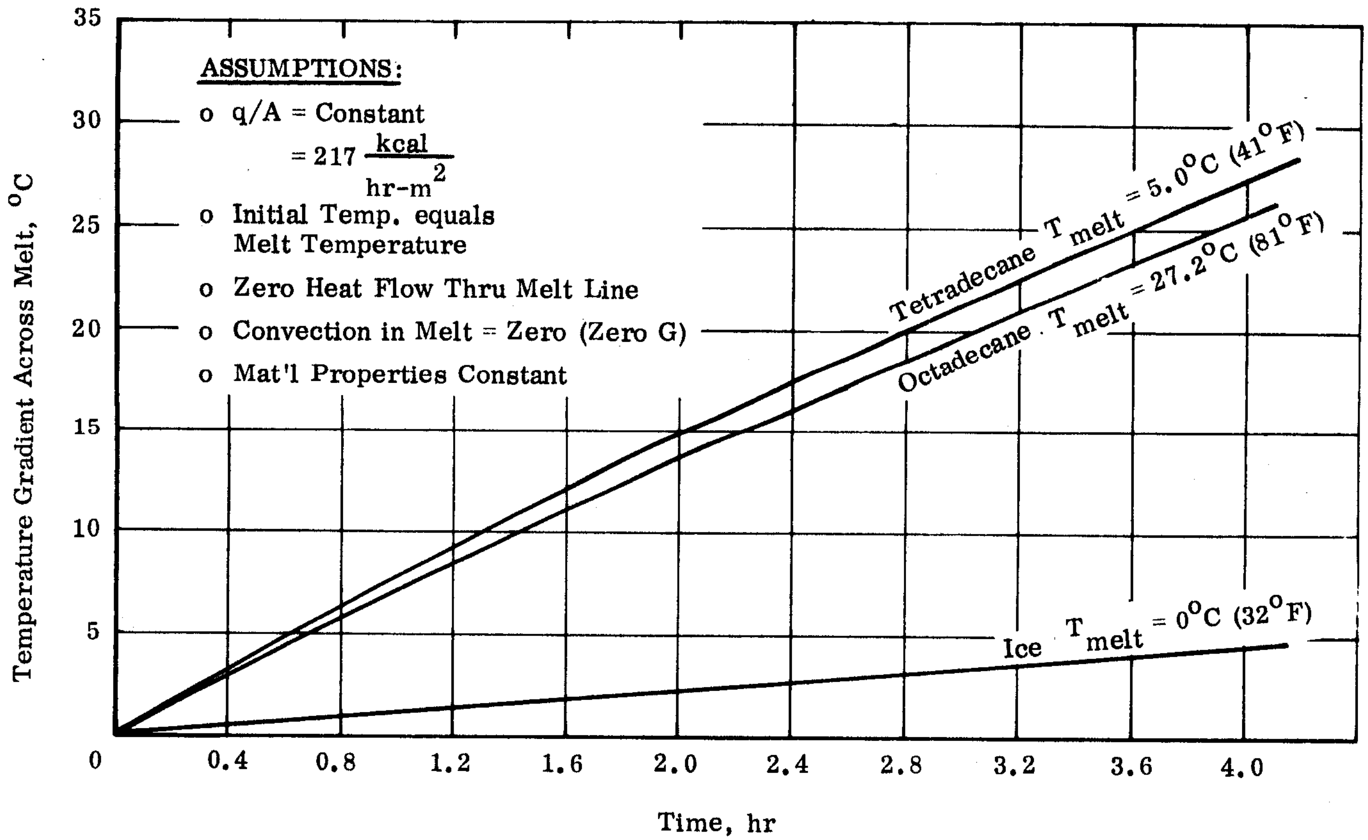


FIGURE 5 TEMPERATURE GRADIENT ACROSS THE LIQUID MELT OF FUSIBLE MATERIALS AS A FUNCTION OF OPERATING TIME FOR A CONSTANT HEAT RATE

The adaptability of two fusible materials, water (ice) and octadecane, to change in sensible metabolic heat rates is shown in Figure 6. This figure shows instantaneous skin temperatures versus sensible metabolic heat rates for three time points of suit operation. A constant thermal resistance is assumed between the fusible materials and the skin such that at time zero and with a sensible heat flow of 201.6 $\frac{\text{kilocalories}}{\text{hr}}$ (800 BTU/hr) from the skin, the skin temperature is 33.1° C (91.5° F). For time equal to zero, Figure 6 indicates that with octadecane the variation of skin temperature is within the allowable limits for a fairly large range of sensible heat flows. However, for time periods of a half hour or more, the effects of the liquid layer build-up results in octadecane becoming less adaptable to changes in metabolic rates as indicated by a change in slope of the curve. In addition, the level of metabolic rates which can be handled falls to marginal levels. Figure 6 indicates that although water is less adaptable to a range of metabolic rates for the time periods indicated on the curve, the level of metabolic rate that can be handled does not change with time as rapidly as it does for octadecane. The higher effective thermal conductance of the liquid water layer accounts for the smaller effects on heat rate with time for the water. The higher melting temperature accounts for the greater adaptability to a variation of metabolic rates for the octadecane.

Table II presents a summary of the performance of octadecane and water in the space suit application.

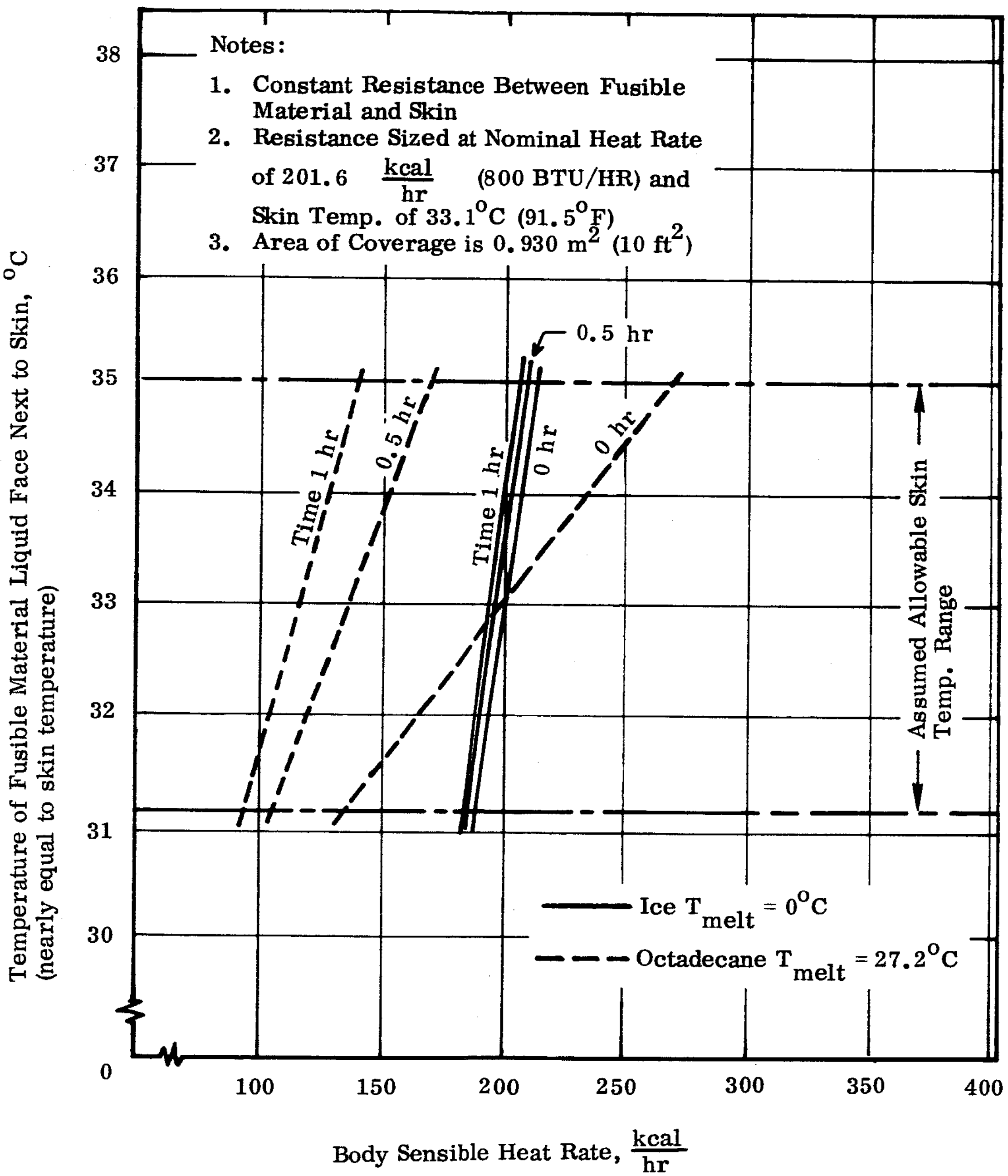


FIGURE 6 SKIN TEMPERATURE VARIATION AS A FUNCTION OF BODY SENSIBLE HEAT RATE FOR SEVERAL FUSIBLE MATERIALS

TABLE II

PERFORMANCE OF WATER (ICE) AND OCTADECANE AS FUSIBLE HEAT SINK MATERIALS FOR A SPACE SUIT

MATERIAL	For a Sensible Metabolic Heat Rate of $201.6\ \frac{\text{kilocalories}}{\text{hr}}\ \left(800\ \frac{\text{BTU}}{\text{hr}}\right)$	
	Operating Time	Material Required for 1/2 hr Operation
WATER	4 hours	1.25 kg (2.76 lbs)
OCTADECANE	1/2 hour	1.92 kg (4.23 lbs)

MATERIAL	Allowable Range of Body Sensible Heat Rates for assumed Skin Temperatures Between 31.1^{o} to 35^{o}C (88^{o} to 95^{o}F)		
	Instantaneous (Time Zero) kilocalories/hr (BTU/hr)	After 1/2 hour kilocalories/hr (BTU/hr)	After 1 hour kilocalories/hr (BTU/hr)
WATER	189.0 - 214.2 (750 - 850)	185.2 - 209.2 (735 - 830)	184.0 - 206.6 (730 - 820)
OCTADECANE	135 - 268.4 (535 - 1065)	105.8 - 170.1 (420 - 675)	94.5 - 139.9 (375 - 555)

RECOMMENDATIONS

The investigations discussed so far have identified the requirements and heat sink materials for space suit temperature control. They do indicate the need for either modification of the conceptual arrangement shown in Figure 2 or acceptance of the performance limitations.

Basic approaches for adapting fusible materials to space suit temperature control application are:

1. Use a fusible material in an arrangement as shown in Figure 2 and accept a limitation in operating time and in the range of sensible metabolic heat rate.

2. Develop a method of varying the thermal conductance between the fusible material and the skin and use water (ice) or a fusible material with equal or better liquid conductivity, heat of fusion and equally low melt temperature.

3. Use a fusible material with a melting point close to the desired skin temperature in combination with a technique for removing the liquid melt layer and maintaining thermal contact between skin and the melting solid surface.

4. Use a fusible material with a melting point close to the desired skin temperature and increase the effective thermal conductance through the liquid layer.

The limitations imposed in the first approach have already been summarized in Table II. Assuming that these are acceptable for a specific mission application, the weight of octadecane for the 1/2 hour operating time, for a sensible metabolic heat rate of 201.6 kilocalories/hour (800 BTU/hour) would be 1.92 kg (4.23 lbs). The fusible material would be applied to cool approximately one half of the total body area, i.e. 0.93 meter^2 (10 ft^2). The melt layer thickness formed during this period, which equals the useful thickness of the fusible material, would be 2.66 mm (0.105 inch).

By using water (see Table II), the useful operating time of the suit is of more adequate duration (four hours) for a nominal sensible heat rate of 201.6 kilocalories/hr (800 BTU/hr). The weight of water required is approximately 10 kg (22.1 lbs) applied over a 0.93 m^2 (10 ft^2) area. The limitation for this material is the low range of variations of metabolic sensible heat rates which can be handled.

The variable conductance required for the second approach would be a means to increase the possible range of heat rates. Figure 7 shows the variations in thermal conductance required to maintain the skin temperature at 33.1° C (91.5° F). For a desired range of suit operation from 101 to 252 kilocalories/hour (400 to 1000 BTU/hr) and an operating time of 4 hours, a thermal conductance which can vary between 0.33 and 1.03 calories (gm)/hour - cm^2 - ^{o}C is required. A suit arrangement using multiple foils of crinkled aluminized mylar as the variable resistance is shown in Figure 8. Here, the contact areas between the sheets of mylar would be increased

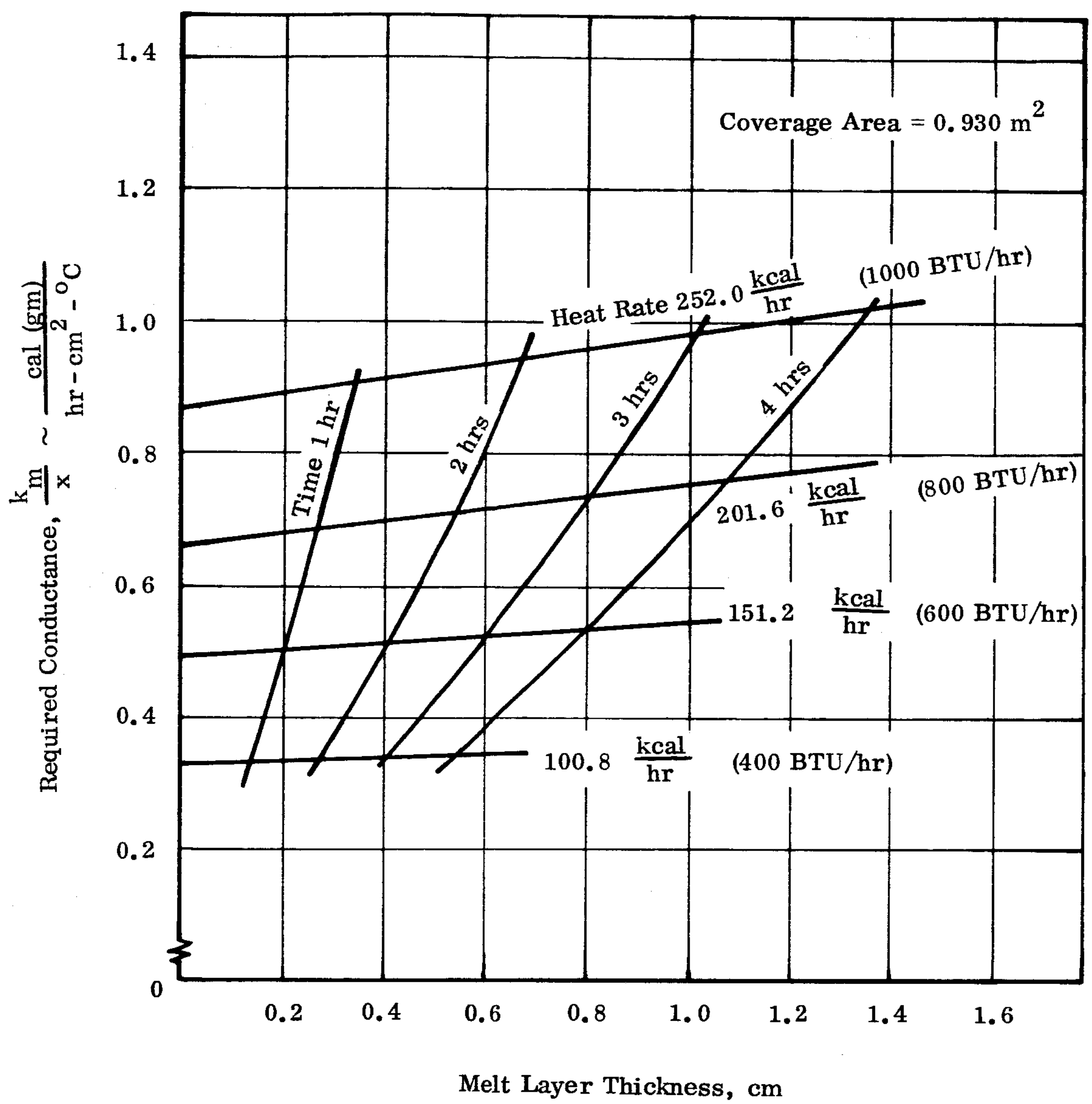


FIGURE 7 VARIABLE CONDUCTANCE REQUIRED TO MAINTAIN SKIN TEMPERATURE AT 33.1°C AS A FUNCTION OF FUSIBLE MATERIAL (WATER) MELT LAYER THICKNESS FOR SEVERAL BODY SENSIBLE HEAT RATES

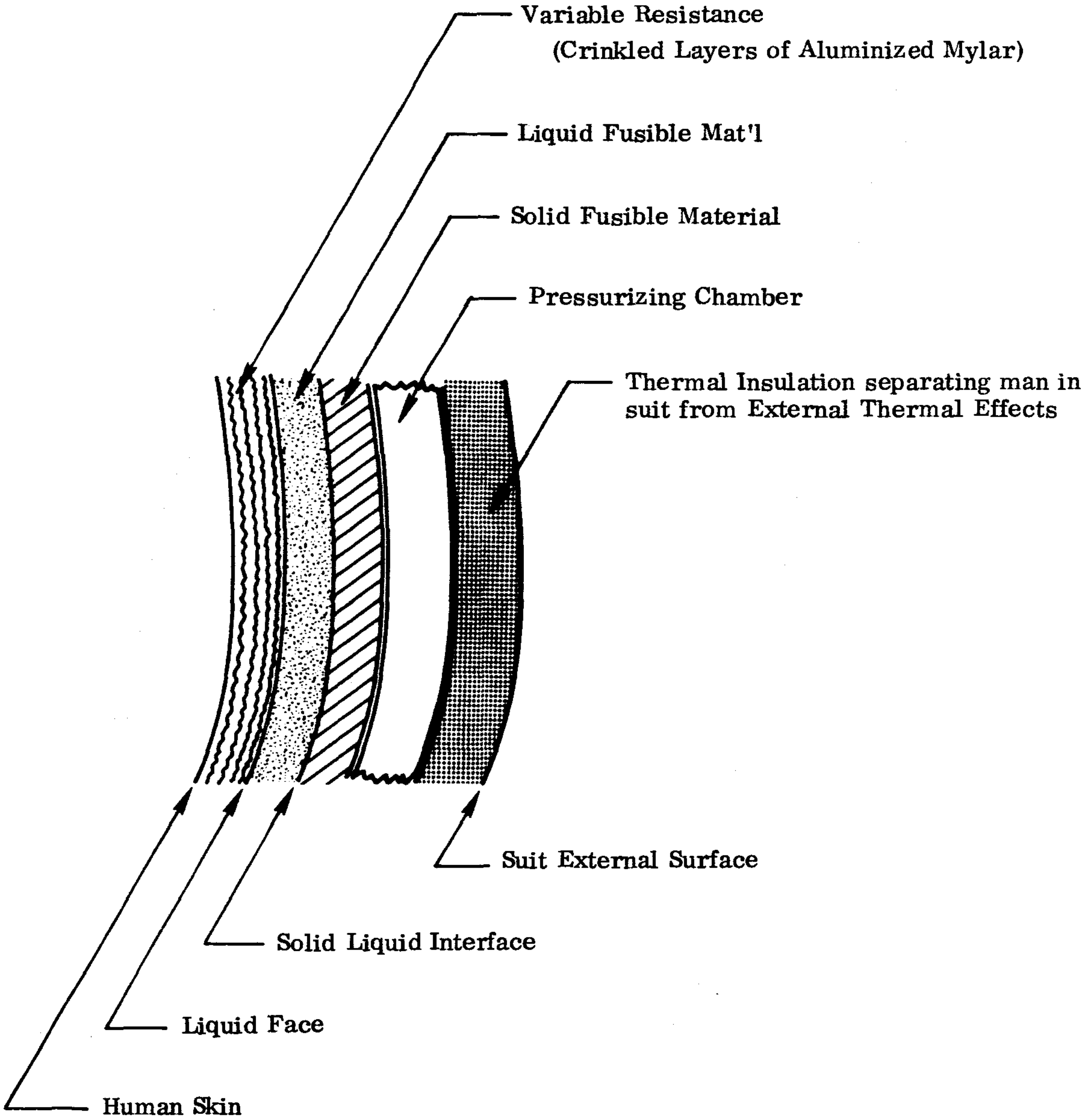


FIGURE 8 CONCEPTUAL SKETCH OF SCHEME TO REMOVE BODY SENSIBLE HEAT, UTILIZING A VARIABLE RESISTANCE

with applied pressure, thus increasing the thermal conductance. Analytical determination of the feasibility of this variable resistance has not been performed due to the difficulty of evaluation of such a complex and uncertain model of contact resistance.

Any technique of varying thermal conductance will require sensing of metabolic rate or skin temperature and active control of the variable thermal conductance device. Much of the desired simplicity and reliability of the basic concept would thereby be lost.

In the third approach, a method of removing the melt layer of octadecane has been devised. Figure 9 illustrates conceptually a method of accomplishing this. While this approach is not fully passive, it can be made to be self actuated during suit operation. Its major advantage is that it minimizes thermal resistance between the constant temperature melting solid surface and the skin. By selecting a fusible material of a melt temperature just below the desired skin temperature, skin temperature variations resulting from changing metabolic heat rate will be minimized. Adaption to variations in metabolic rate is provided passively and results from the fact that heat absorption by phase change is a constant temperature process.

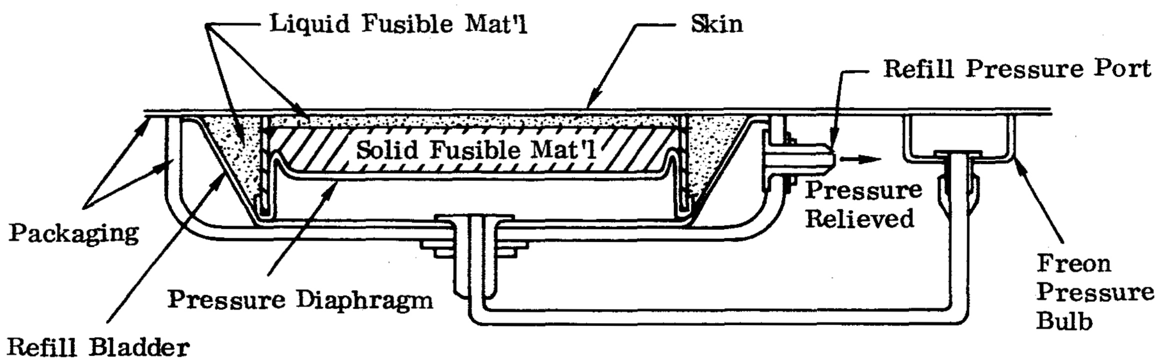
During the operating cycle of the space suit the melt layer is squeezed into the "Refill Bladder" by forcing the solid fusible material toward the skin. Regeneration of the space suit will require warm soak of the suit to melt the fusible material and application of external gas pressure at the refill pressure ports. Gas pressure acting on the refill bladder will force the liquefied fusible material into the center compartment of the device. Cooling and solidification of the fusible material will then prepare the suit for another operating cycle.

The basic concept shown could be applied to fusible material containers of various shapes, as required for mobility and proper distribution of heat sinks in the space suit. Each container would operate as an independent unit. The approach is considered as promising and feasible. Application to practice will require development of space suit hardware.

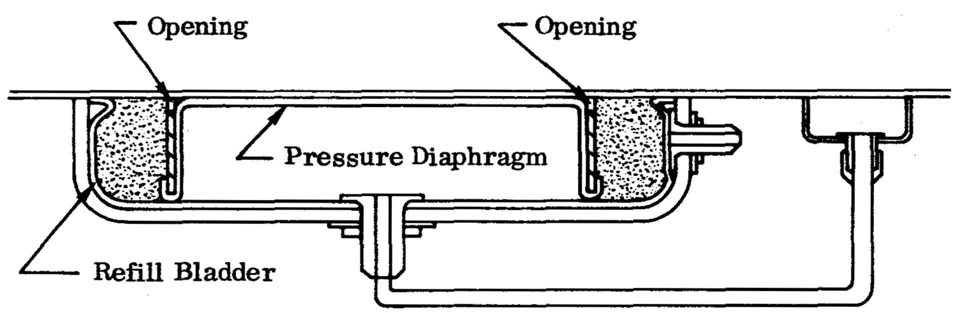
The fourth approach, i.e. increase of the effective thermal conductance of the liquid fusible material leads to a variety of concepts. Included are the use of filler materials such as aluminum or copper flakes, thermally conductive fins extending from the container wall which is in contact with the skin into the fusible material, thereby providing a thermal bridge across the melt layer, or finding materials with inherently higher thermal conductivity than the paraffins so far investigated.

The effect of an increase in effective thermal conductance of octadecane upon temperature difference across the liquid melt layer is shown in Figure 10. As this figure shows, the operational time of the suit would be increased to 2.0 hours for a change in skin temperature of 3.9°C (7°F), if the liquid melt layer effective conductance is increased by a factor of 4.

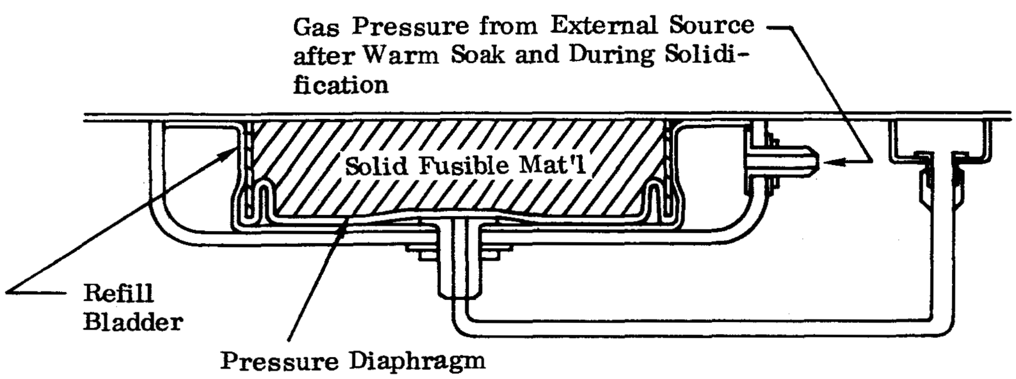
Materials of interest because of potentially higher thermal conductivity include hydrated salts which undergo on heat addition an endothermic change from a crystalline solid to an amorphous liquid phase. Thermal conductivities equal to or higher than water can be expected. However, in addition to finding and selecting materials of the required phase change temperature and heat of phase change, recrystallization behavior on heat removal, as is required for reactivation of the space suit heat sink, requires further investigations.



HEAT ADDITION CYCLE: Approx. Half of Cycle Time Elapsed



HEAT ADDITION CYCLE: Cycle Completed - Fusible Material has been Forced by Pressure Diaphragm and Freon Vapor Pressure into Refill Bladder



REGENERATION CYCLE: Cycle Completed Ready for New Heat Addition Cycle

FIGURE 9 CONCEPTUAL SKETCH OF SCHEME TO IMPROVE PERFORMANCE BY REMOVING THE LIQUID MELT

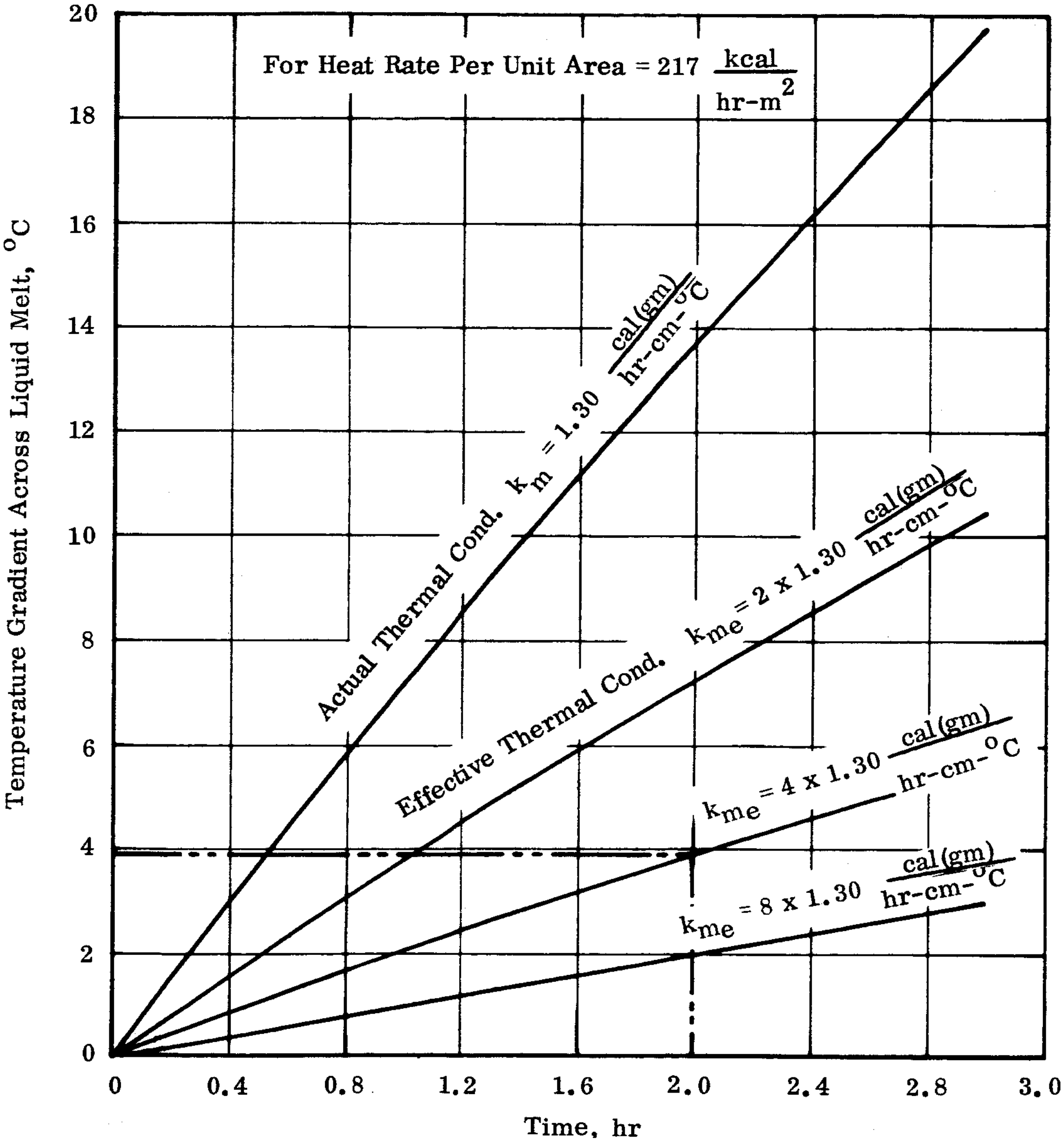


FIGURE 10 TEMPERATURE GRADIENT ACROSS THE LIQUID MELT OF OCTADECANE AS A FUNCTION OF TIME FOR SEVERAL FACTORS OF INCREASE IN APPARENT THERMAL CONDUCTIVITY

Modification of the effective thermal conductance, permitting use of materials with a phase change temperature close to the desired skin temperature, shares with approach three the potential of an inherent and passive adaption to variations in metabolic rate.

CONCLUSIONS

Fusible materials of suitable melt temperature and heat of fusion are potentially suitable for application as heat sinks, integrated into the space suit, for control of sensible metabolic heat. Their application is limited as to operating time. In applications where such limited operating time is acceptable, integrating heat sinks into the space suit will result in significant simplifications of the space suit and backpack system.

Ability to store heat in a heat sink is always limited by the mass of material that is acceptable from considerations of weight penalty and bulk. However, the limitations in the space suit result from the formation of a layer of liquid fusible material in the heat path between skin and the melting solid and from the low thermal conductivity of liquid fusible materials, which have been selected from considerations of adequately high heat of fusion, suitable melt temperatures and absence of corrosiveness and toxicity. The melt layer, increasing in depth with heat addition, reduces heat flow with increasing time of suit operation. This also complicates adjustment of the heat removal rate to variations in metabolic heat output. It has been shown that reduction of thermal resistance between a constant temperature melting surface and the skin improves adaptability of the system to variations in metabolic rate.

Several concepts for solution of these problems are presented. The most promising of these are those which reduce the effects of the formation of the liquid melt layer. Further effort, both analytical and experimental, is required to advance these concepts to practice. Given this effort, an integral heat sink space suit, suitable for operating times of several hours and passively adjusting to variations in metabolic rate is considered feasible.

REFERENCES

1. Felder, J. W. and Shlosinger, A. P., "Research on Methods for Thermal Transport in a Space Worker's Garment", Report No. AMRL-TDR-63-90, Aerospace Medical Research Laboratories, Wright-Patterson Air Force Base, Ohio, November 1963.

2. Airesearch Manufacturing Company, "Study of the Thermal Processes for Man in Space", Contract NASW-1015, SS 3280, February 1965.

3. Shlosinger, A. P. and Bentilla, E. W., "Research and Development Study on Thermal Control by Use of Fusible Materials", Interim Report No. NSL 65-16, Northrop Space Laboratories, Hawthorne, California, February 1965.

4. Sax, N. I., "Dangerous Properties of Industrial Materials", Reinhold Publishing Corporation, New York, 1957.

5. Kreith, F., "Principles of Heat Transfer", International Text Book Company, Scranton, Pennsylvania, 1958.